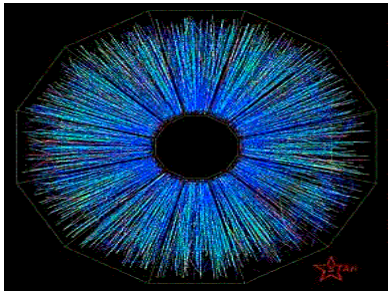


Directed flow from STAR Experiment

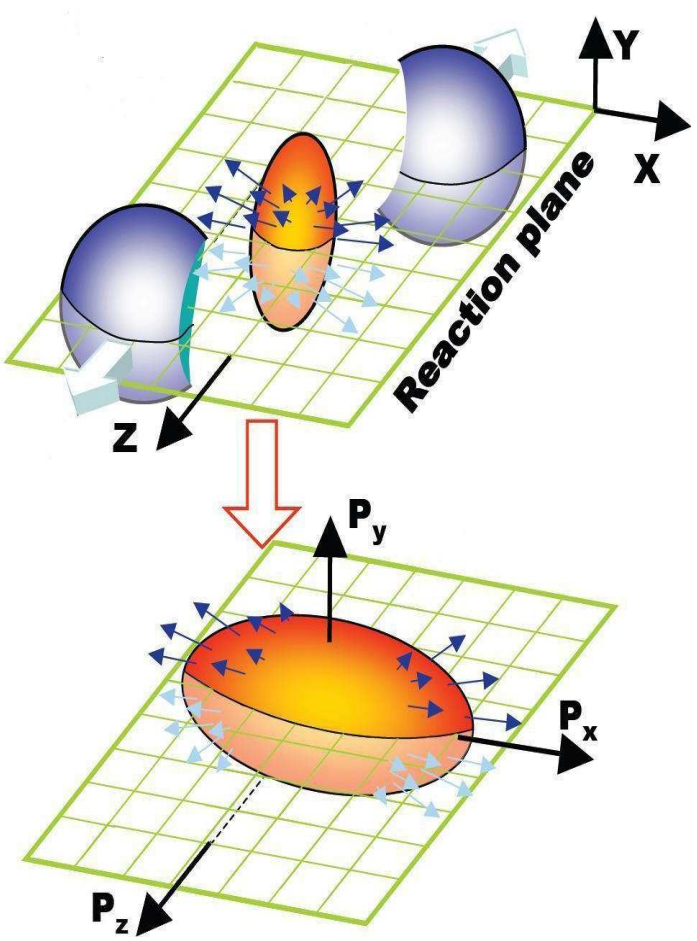
Yadav Pandit (*For the STAR collaboration)*
Kent State University

Outline:

- Introduction
- The STAR Experiment
- v_1 results
  - -62.4 GeV and higher beam energies
  - -39 GeV and lower beam energies
- Summary and Conclusions

Introduction

Anisotropic flow: Anisotropy of the azimuthal distribution of particles with respect to the reaction plane: Fourier expansion of the particle's azimuthal distribution with respect to the reaction plane is given by:



$$E\frac{d^3N}{d^3p} \propto \left(1+\sum_{n=1}^{\infty} 2v_n \cos n(\phi-\Psi_r)\right)$$

Coordinate-Space Anisotropy

$$v_n = \langle \cos n(\phi-\Psi_r)\rangle$$

$$\phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

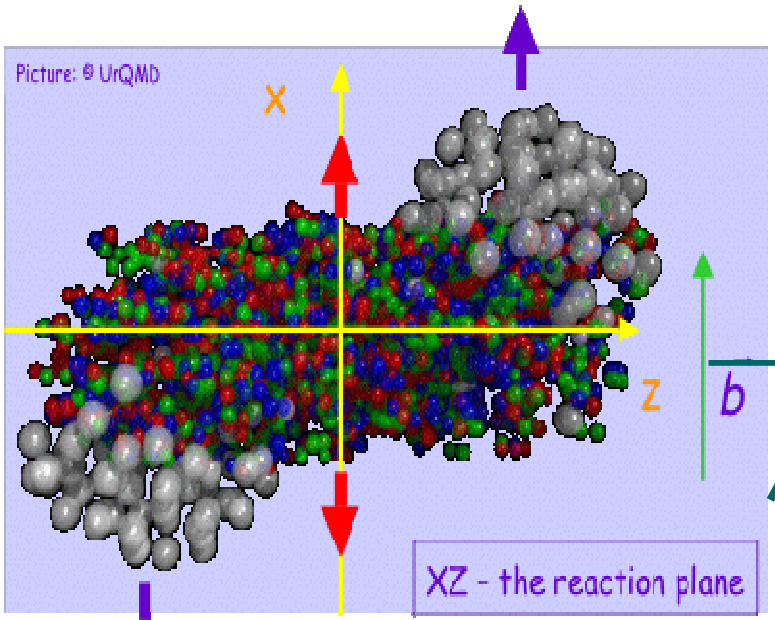
Momentum-Space Anisotropy

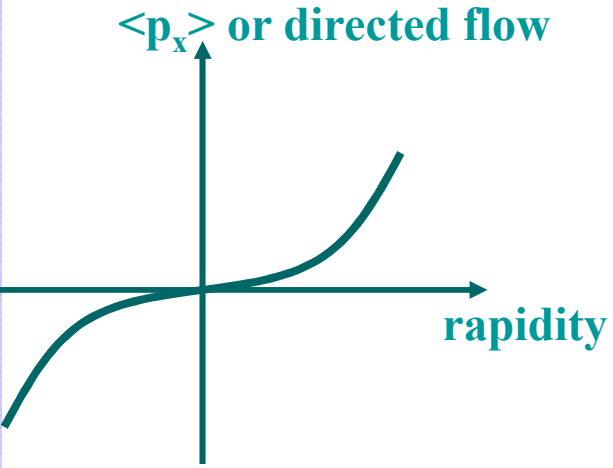
Directed flow (v_1)

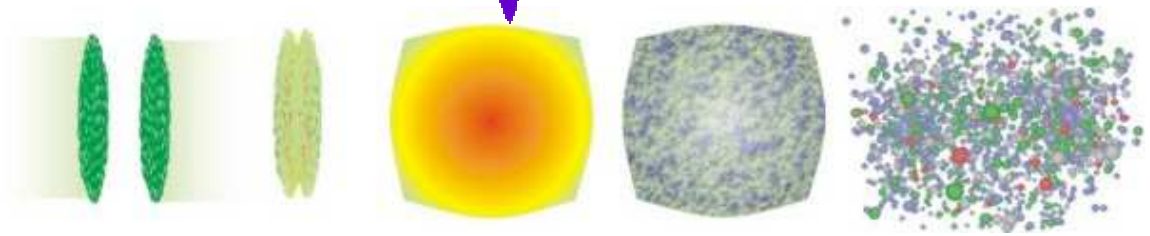
Directed flow is quantified by the first harmonic (v_1)

$$v_1 = \langle \cos(\phi - \Psi_r) \rangle$$

$$\phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$



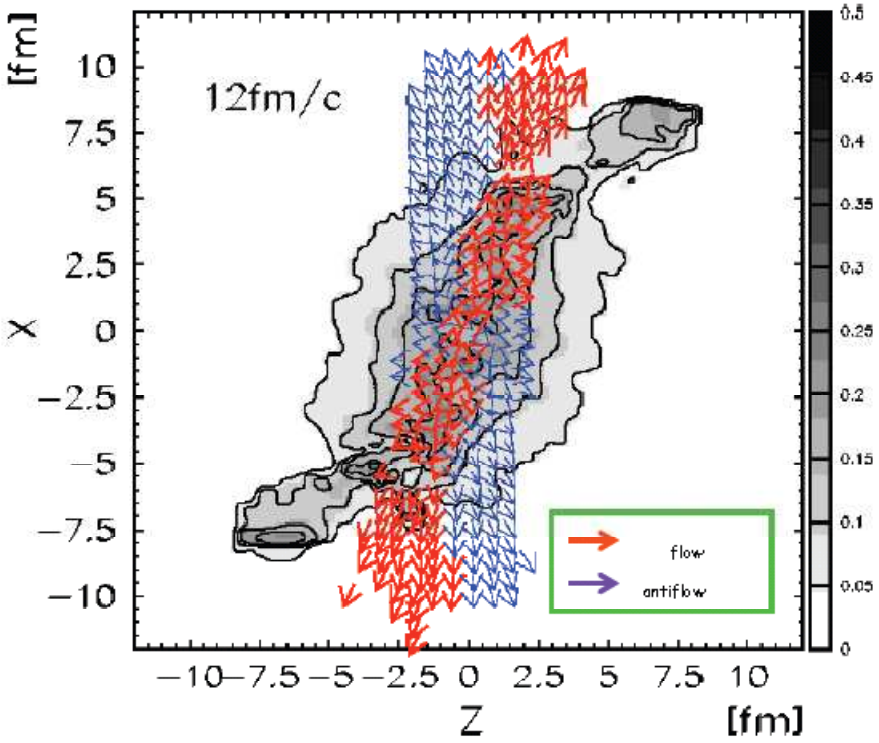


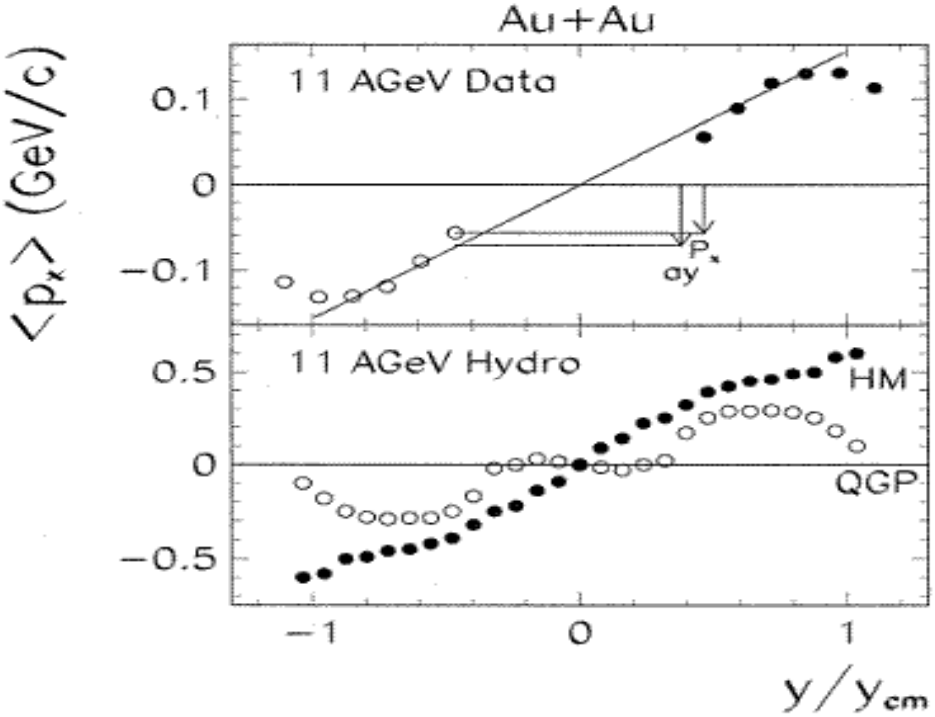


Directed flow (v_1) is generated during the nuclear passage time ($2R/\gamma \sim 0.1$ fm/c) and therefore it probes the very earliest stage of the collision.

$v_1(y)$ Structure

L.P. Csernai, D. Rohrich PLB 458, 454 (1999)

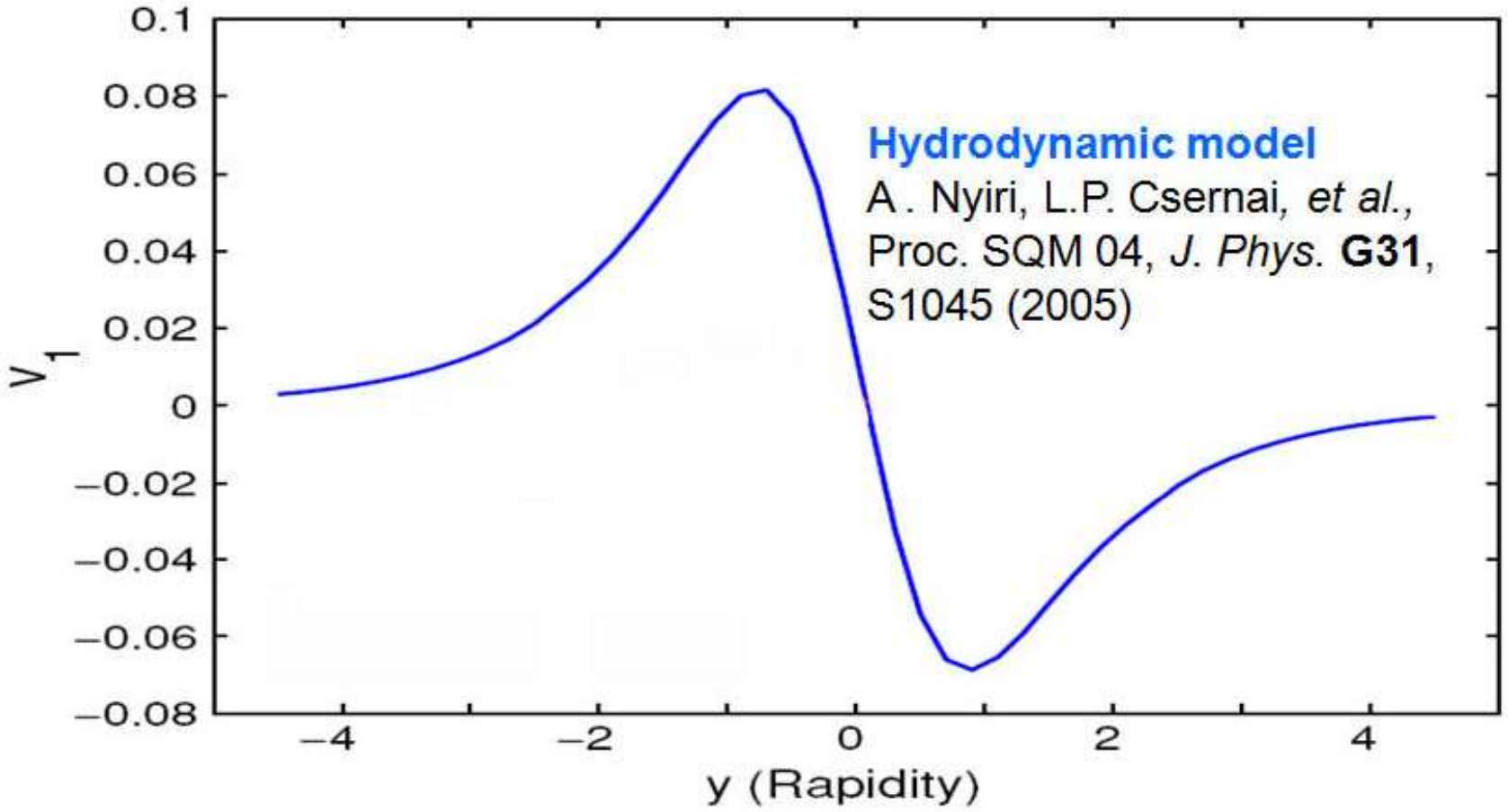




See also J. Brachmann et al., PRC 61, 24909 (2000).

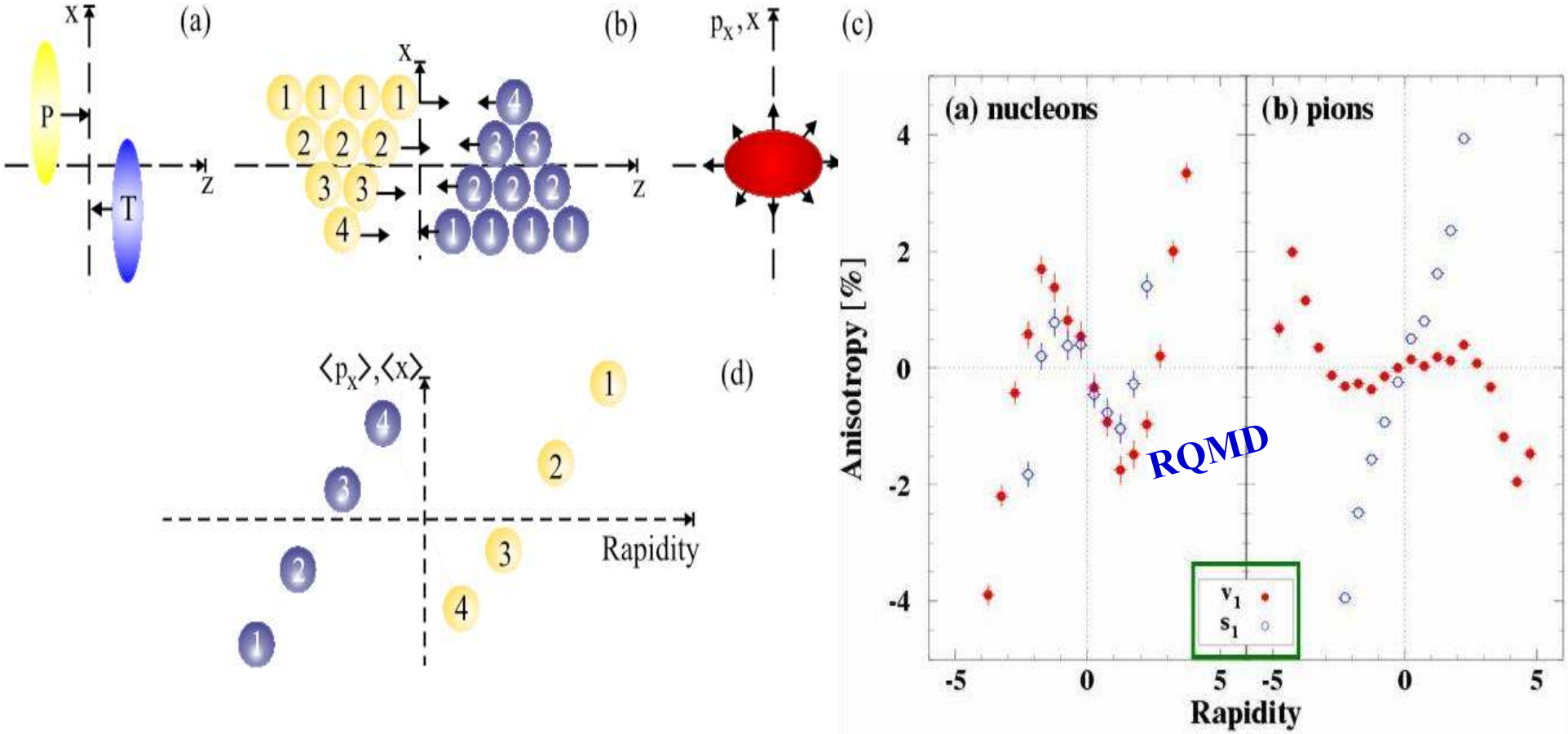
Models predict that anti-flow/3rd flow component, with QGP $\Rightarrow$ $v_1(y)$ flat or crosses zero 3 times (so-called *"wiggle"*).

$v_1(y)$ Structure



Hydro with QGP phase transition shows wiggle

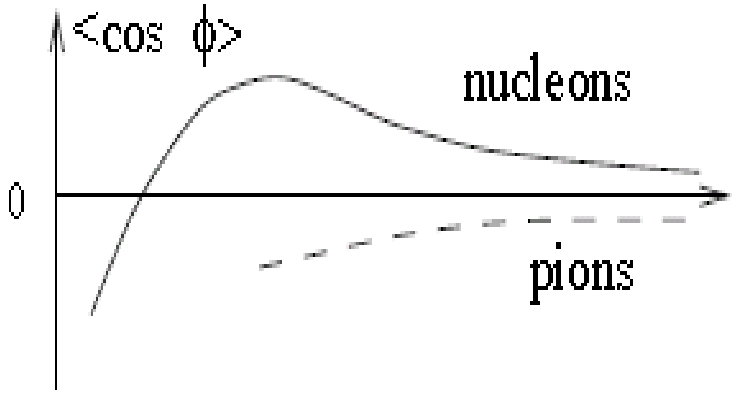
$v_1(y)$ Structure



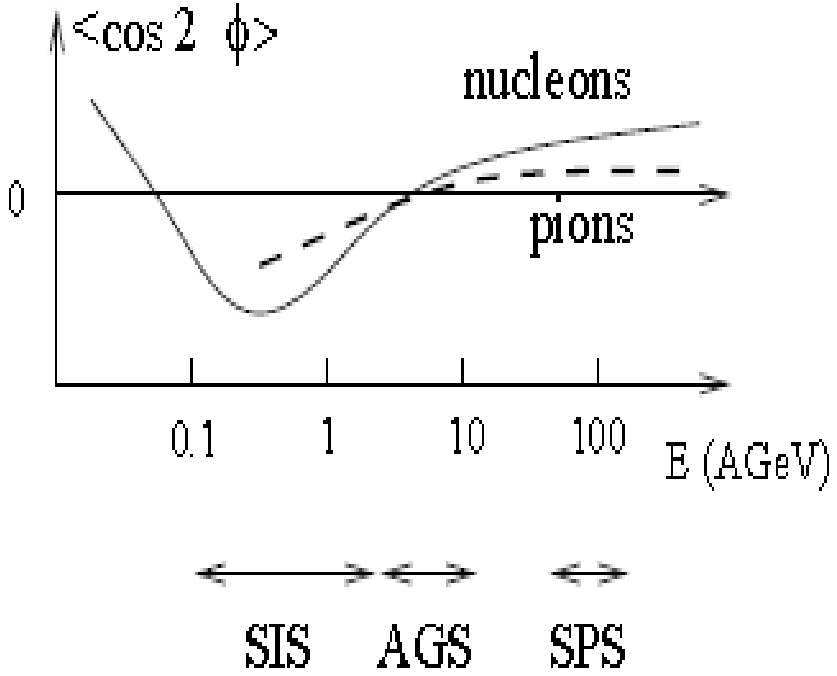
R. Snellings, H. Sorge, S. Voloshin, F. Wang, N. Xu, PRL 84, 2803 (2000)
also H. Liu et al., PRC 59, 348 (1999).

Baryon stopping +positive space-momentum correlation may also give wiggle structure in v_1: NO QGP necessary

v_1: Beam Energy Dependence



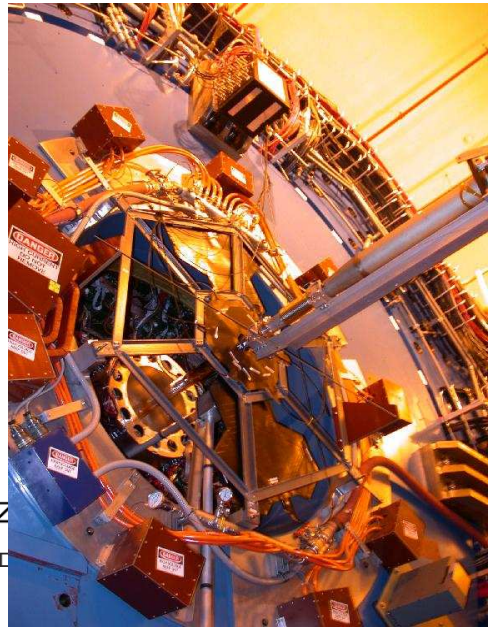
Nucl. Phys. A638, 195c (1998).



As beam energy increases from the SPS region to RHIC, data & models

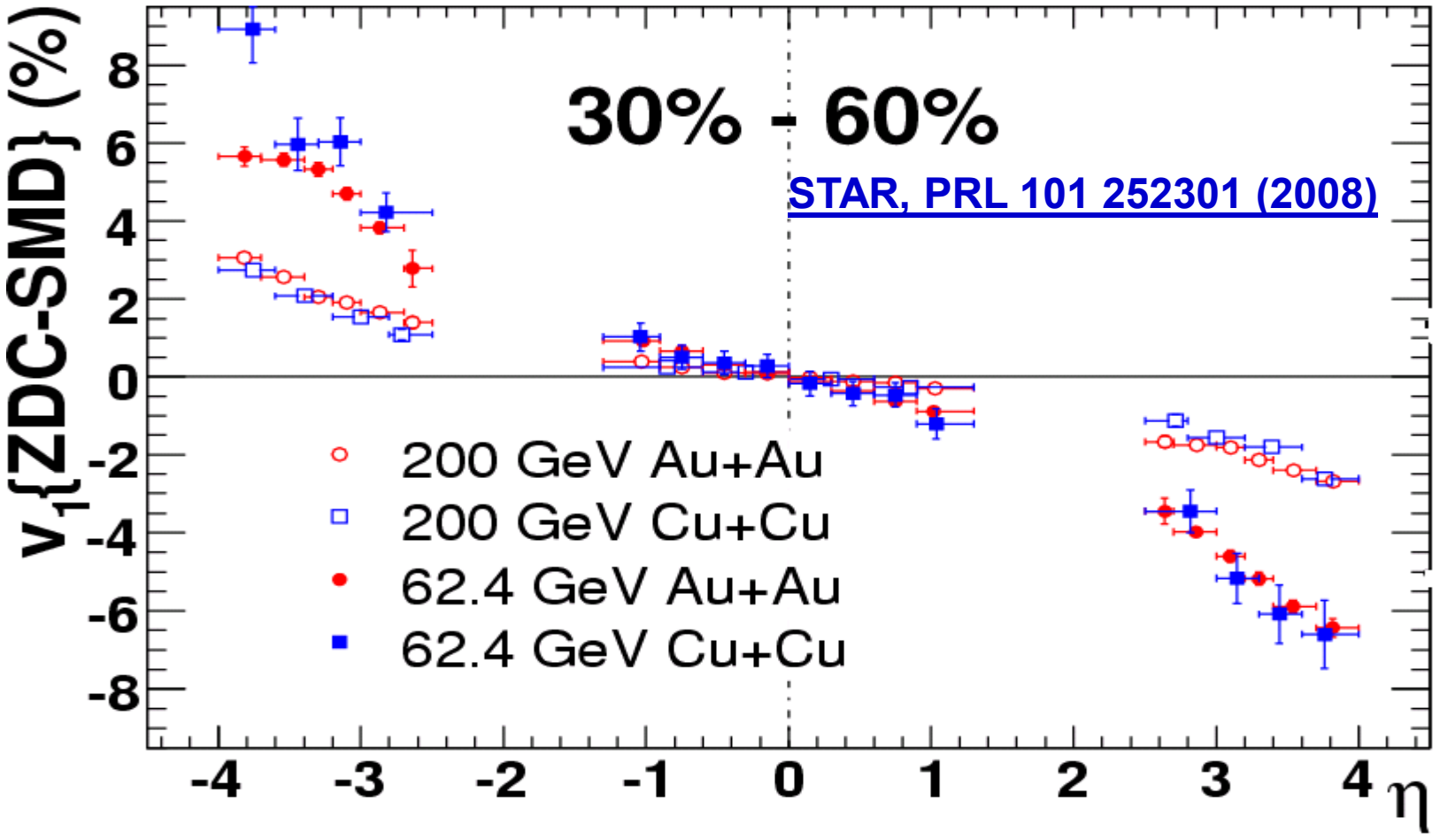
v_2 grows larger while v_1 near mid-rapidity shows opposite trend.

STAR Detector



FTPC(2.2<|η|<4.2) is used to reconstruct the first-order event plane
ZDC-SMD(η>6.4) is used to reconstruct the first-order event plane from spectator neutrons at 62.4 GeV and higher energies
BBC(2.0<|η|<5.0) is used to reconstruct the first-order event plane at 39 GeV and lower beam energies

$v_1(\eta)$ at 62.4 and 200 GeV

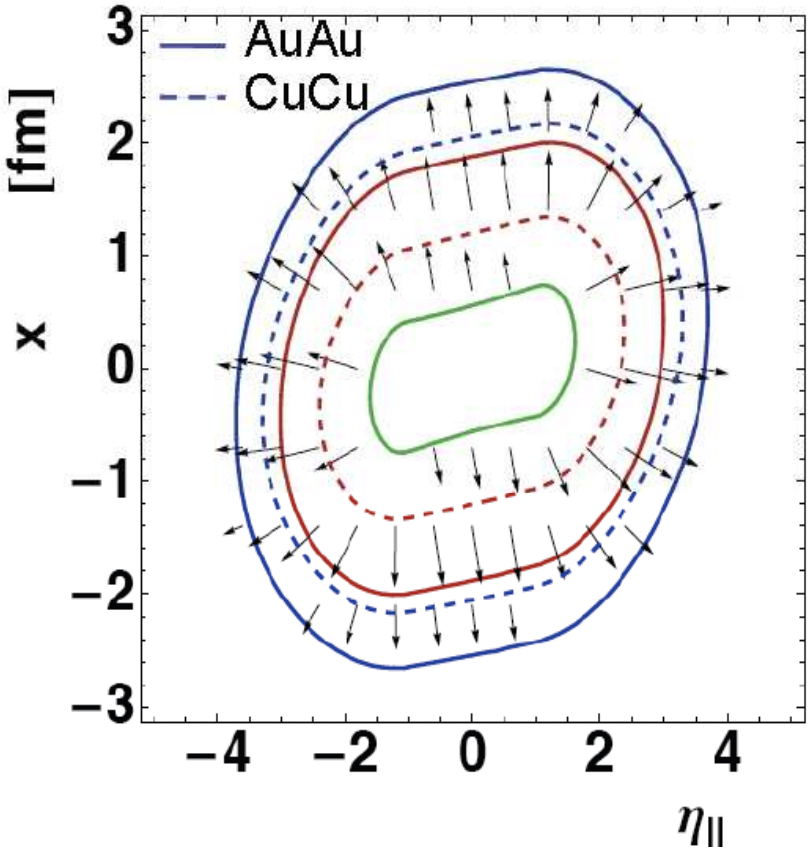


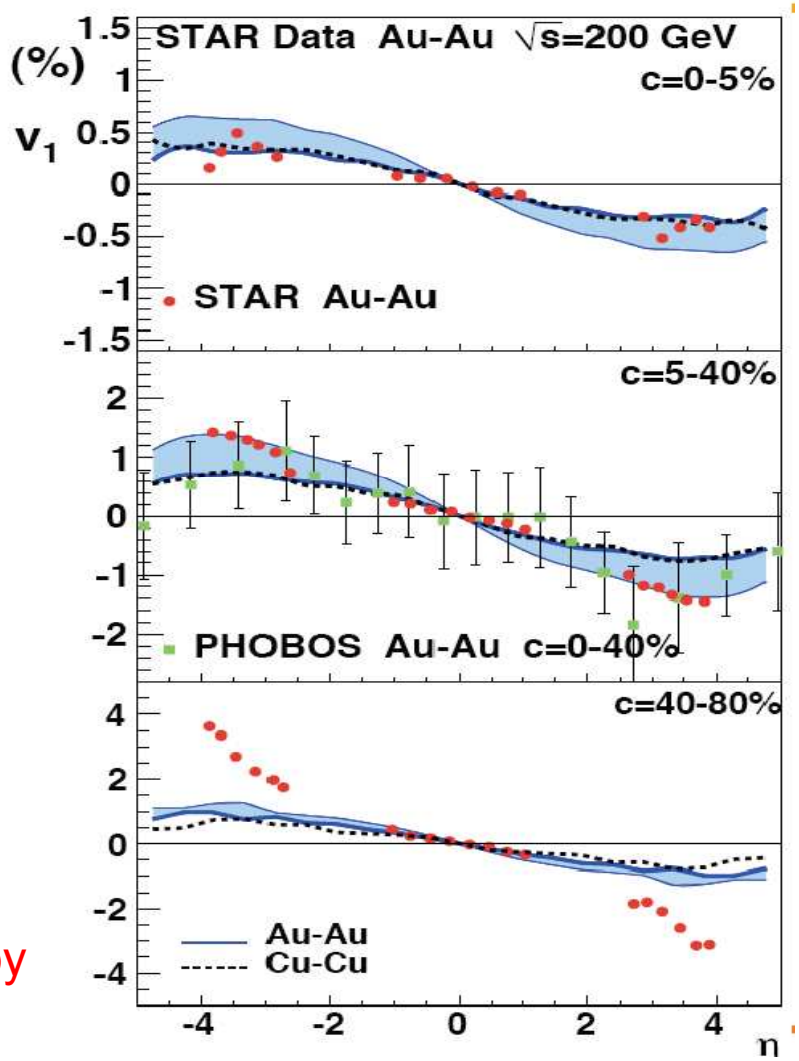
At 62.4 & 200 GeV, no difference within errors between AuAu & CuCu

Beam energy dependence scales with η/y_{beam} (see later)

$v_1(\eta)$ at 200 GeV

P. Bozek & I. Wyskiel, nucl-th/1002.4999

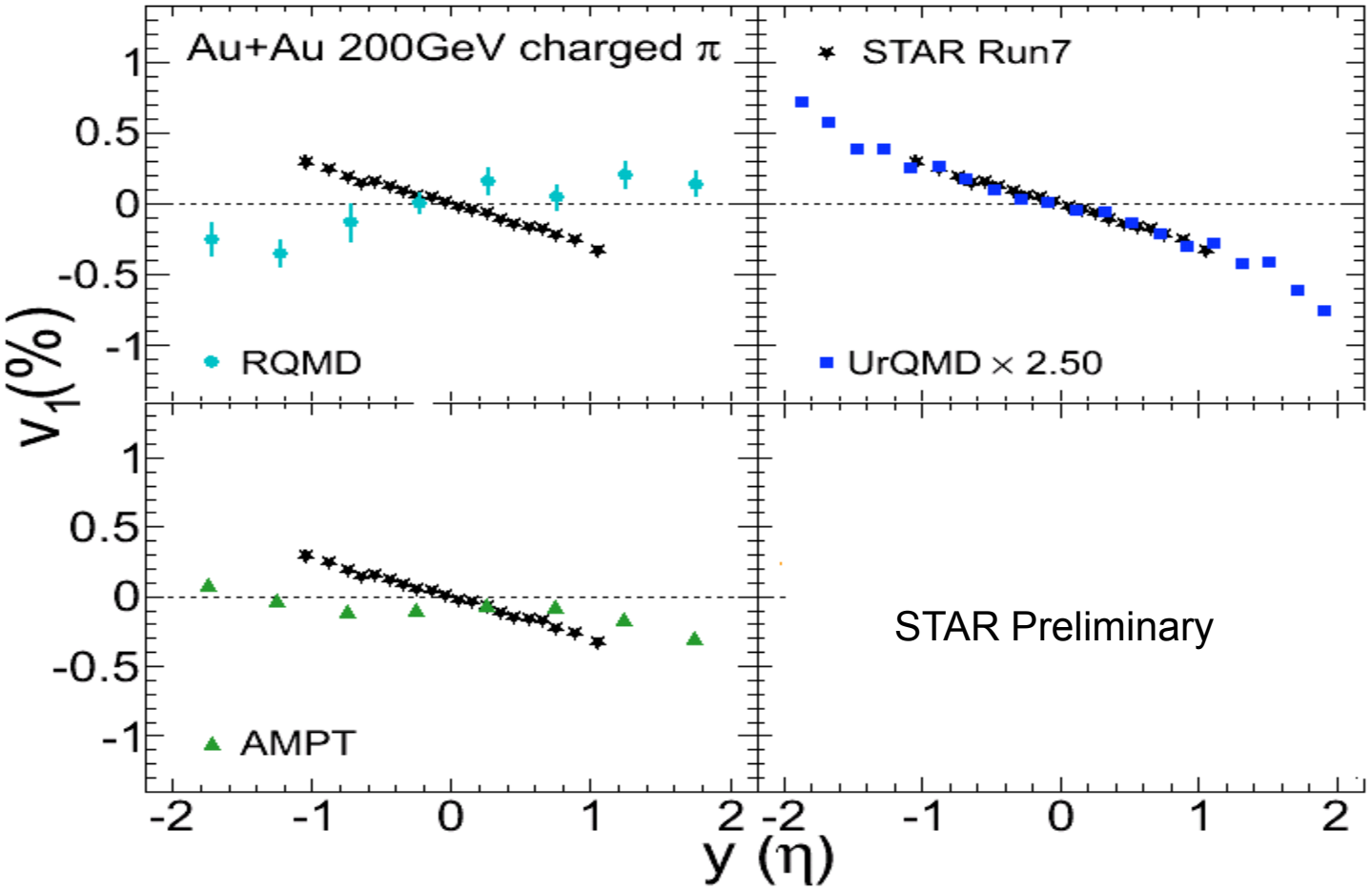




System-size independence for produced particles near midrapidity can be explained by Hydro + tilted source

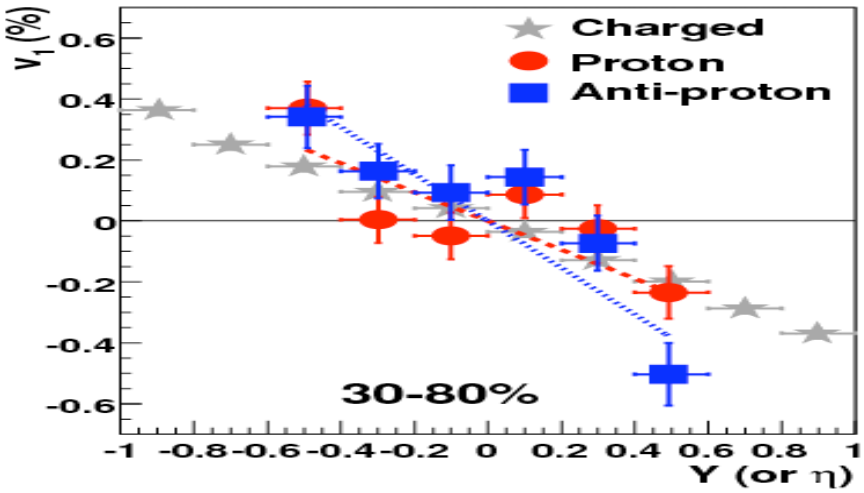
Reflection of similarity in the initial density profiles between AuAu and CuCu.

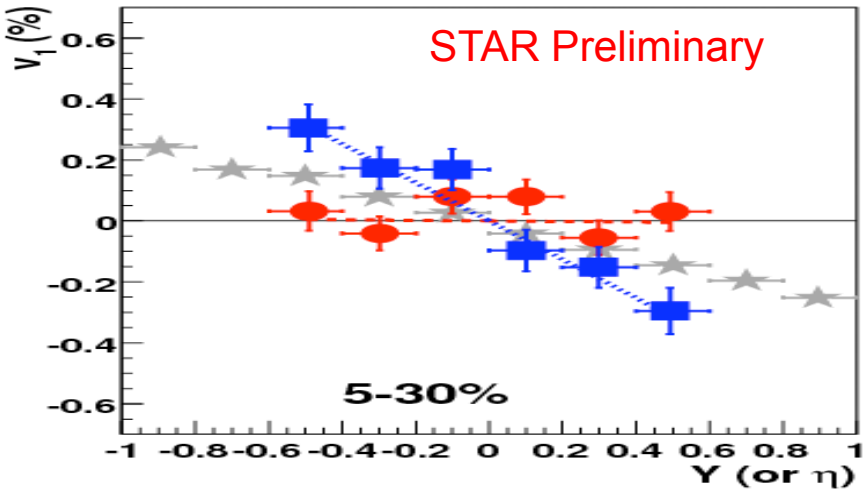
PID v_1 (10-70%) collisions

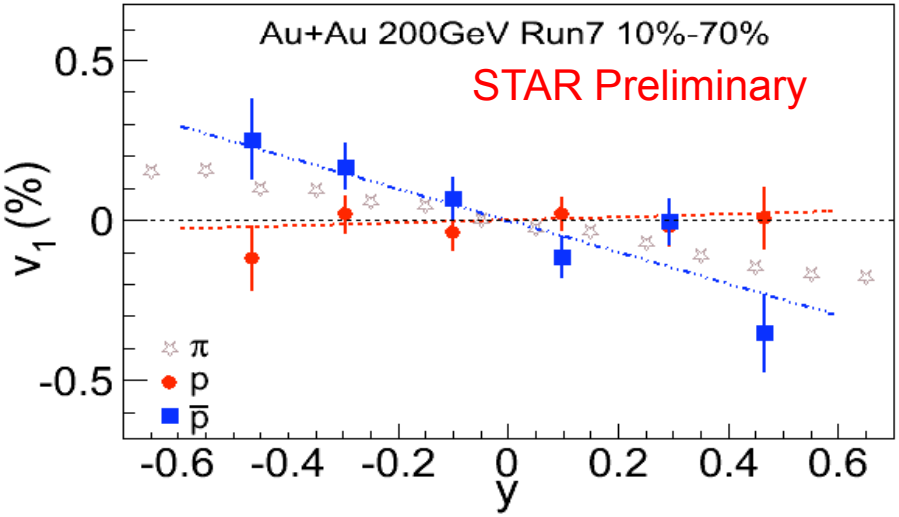


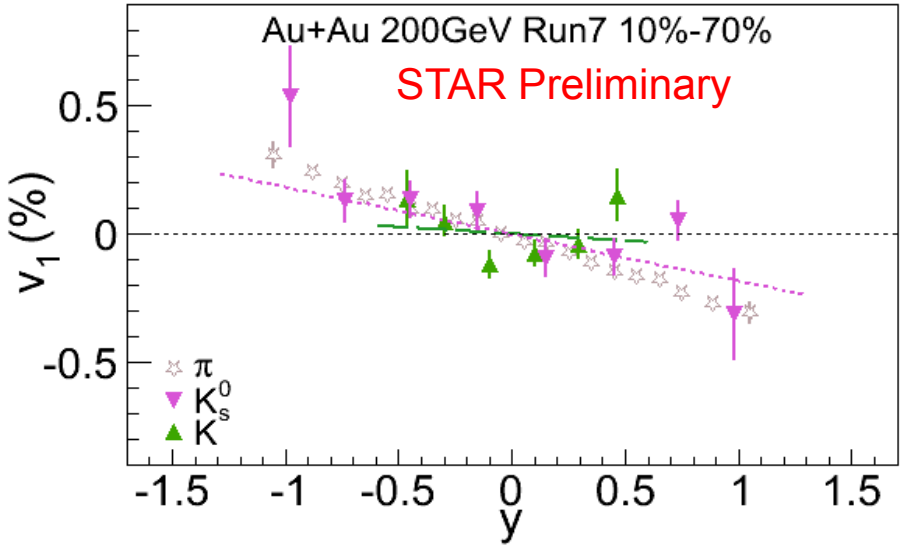
Above models do not explain v_1 magnitude

PID v_1







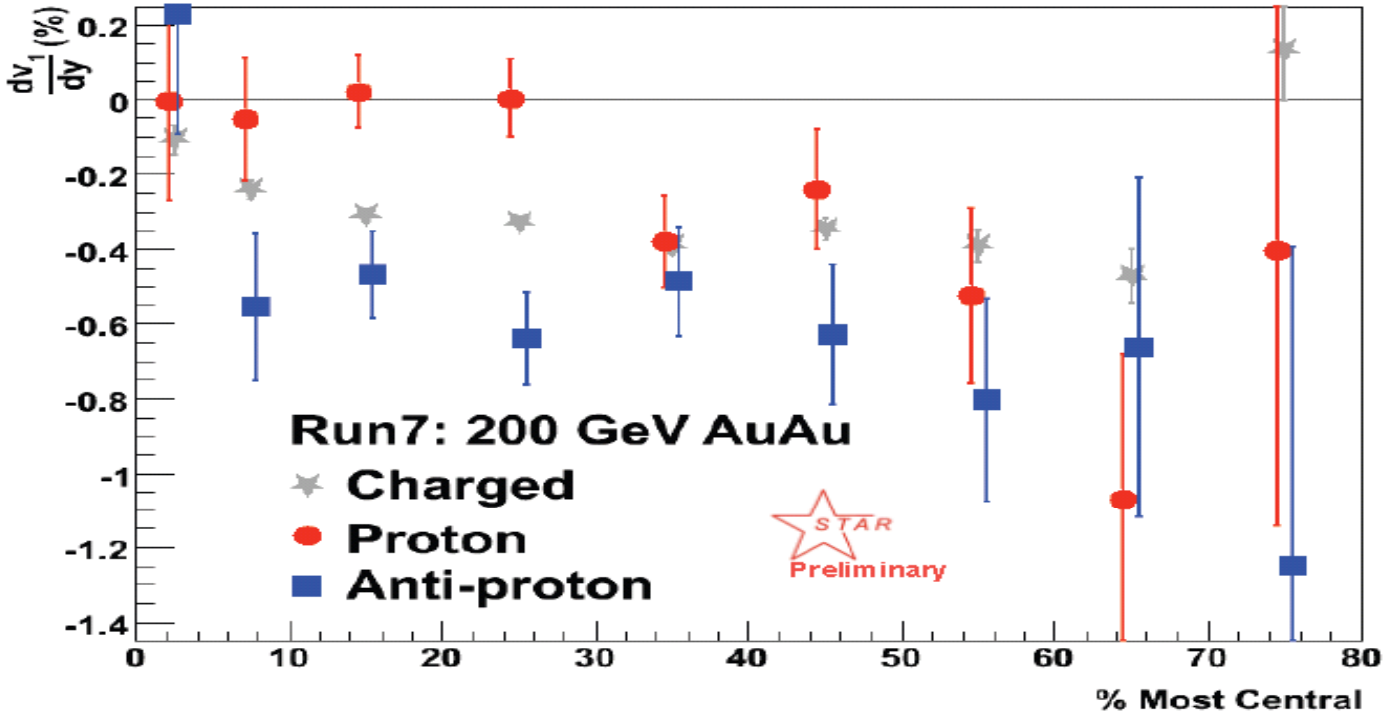


Proton & antiproton *v1* differ in mid-central collisions

Anti-proton slope has the same sign of pions – consistent with anti-flow

Negative *v1* slope for Kshort –consistent with anti-flow

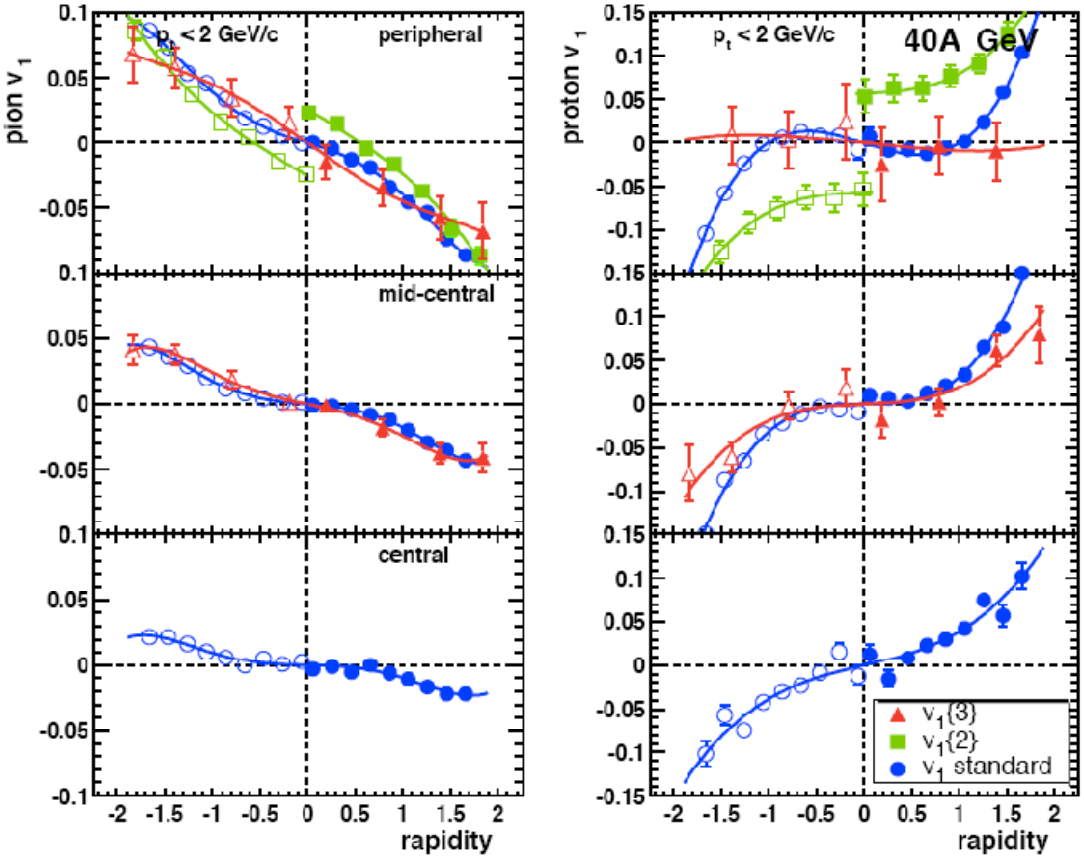
Centrality dependence of v_1 slope



- Negative slope for proton v_1 at 30-80% centrality
- Large difference between proton and antiproton v_1 slope between 5-30% centrality
- Difficult for anti-flow to explain both simultaneously

Directed flow at SPS energies

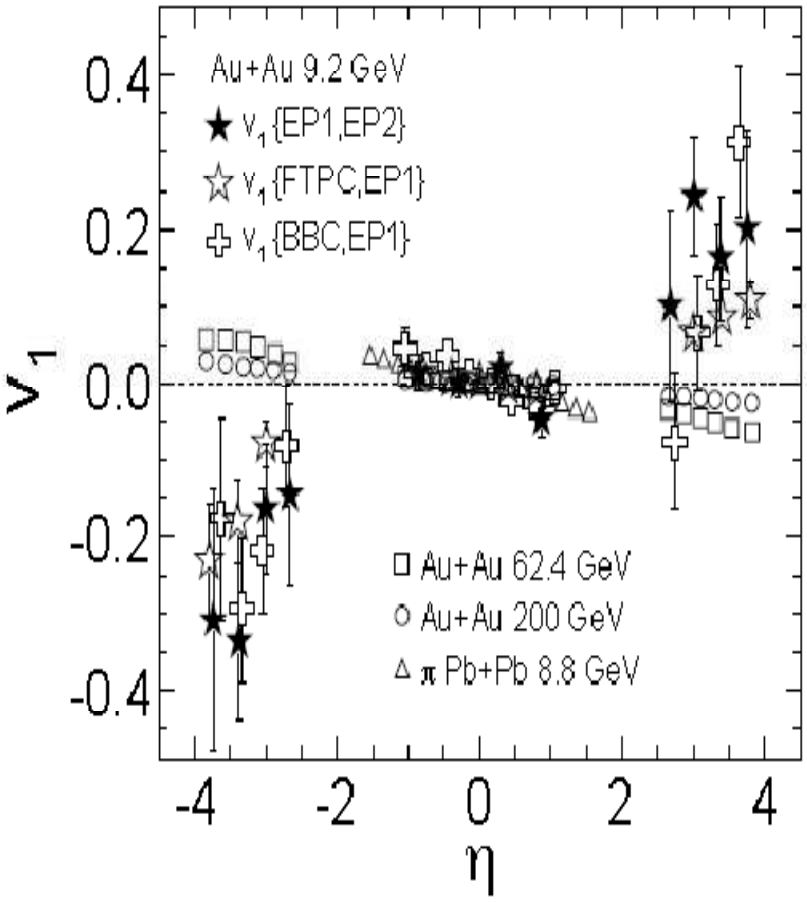
NA49, Phys. Rev. C 68, 034903 (2003)

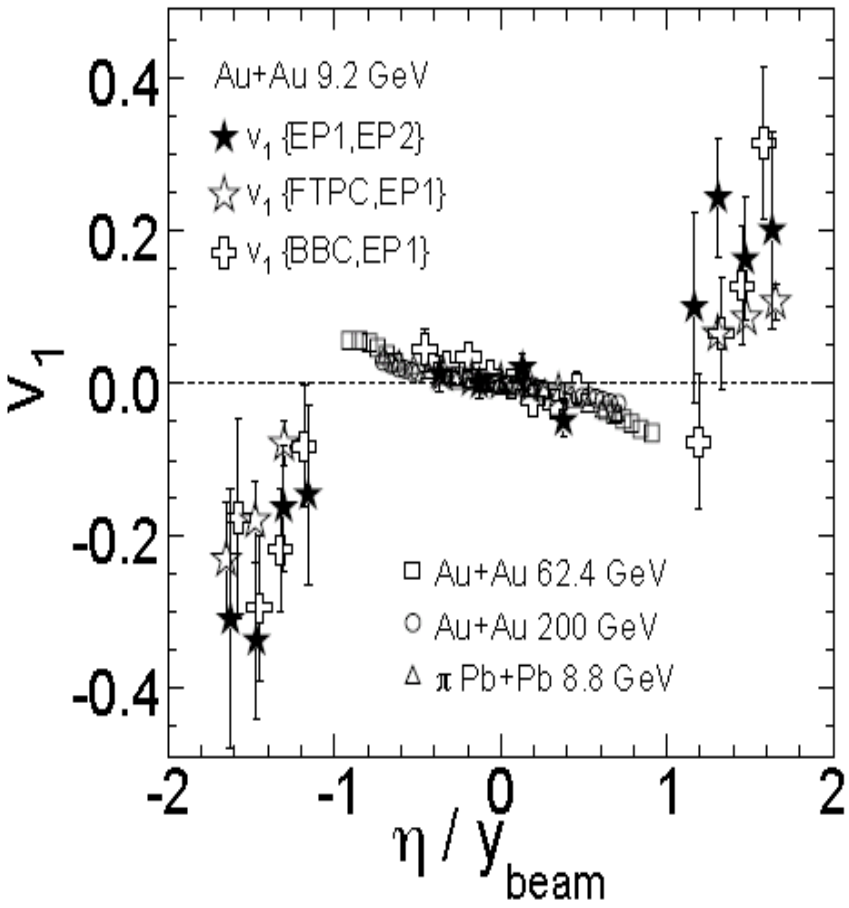


All panels above refer to Pb+Pb at $\sqrt{s_{NN}}$ = 8.8 GeV

Directed flow in 9.2 GeV AuAu Collisions

Phys. Rev. C **81** (2010) 24911



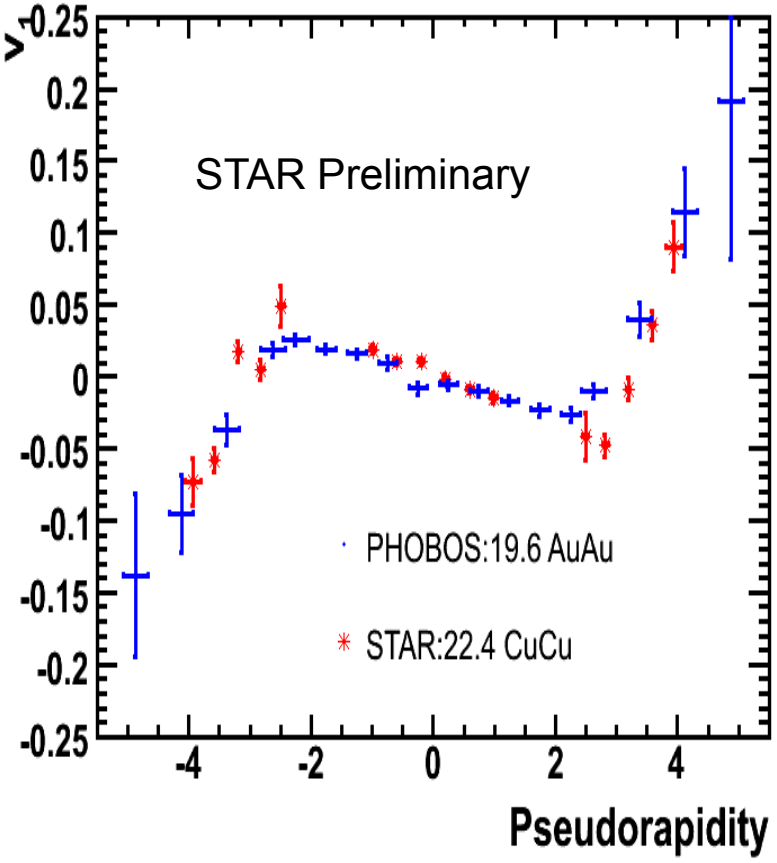


Scaling behavior observed in v_1 vs. η/y_{beam}

Directed flow at 22.4 GeV CuCu (0-60%) Collisions

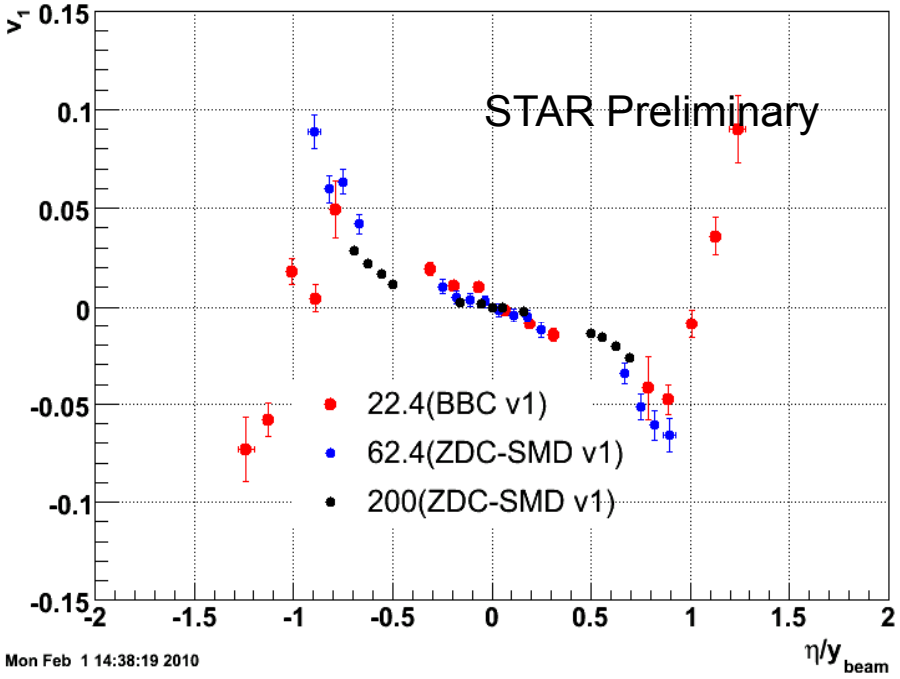
Comparison with PHOBOS

Phys. Rev. Lett. 97, 012301 (2006)



Comparison with STAR

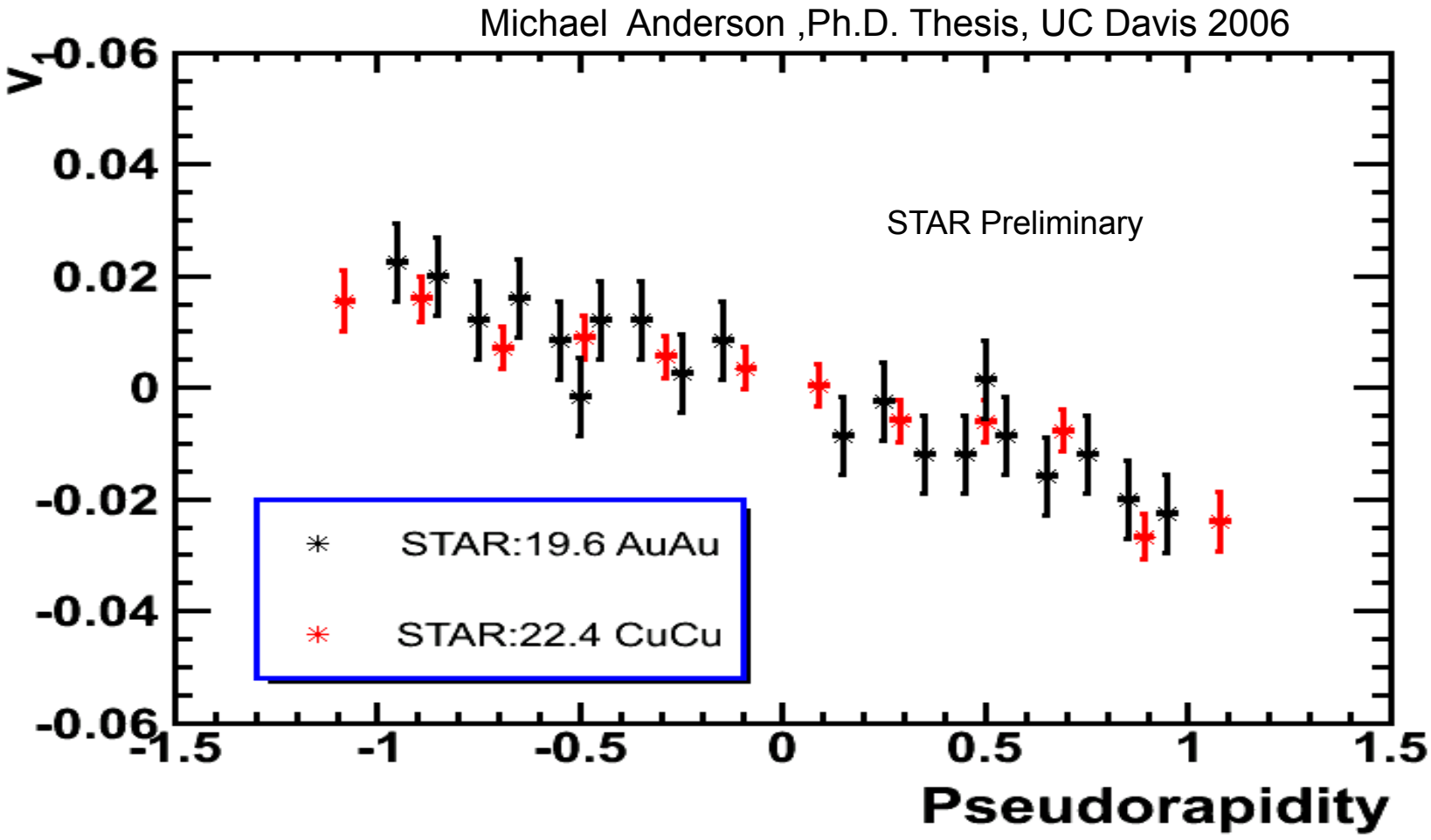
Phys. Rev. Lett. **101** (2008) 252301



y_{beam}=5.4, 4.2, 3.17 for 200, 62.4, 22.4 GeV

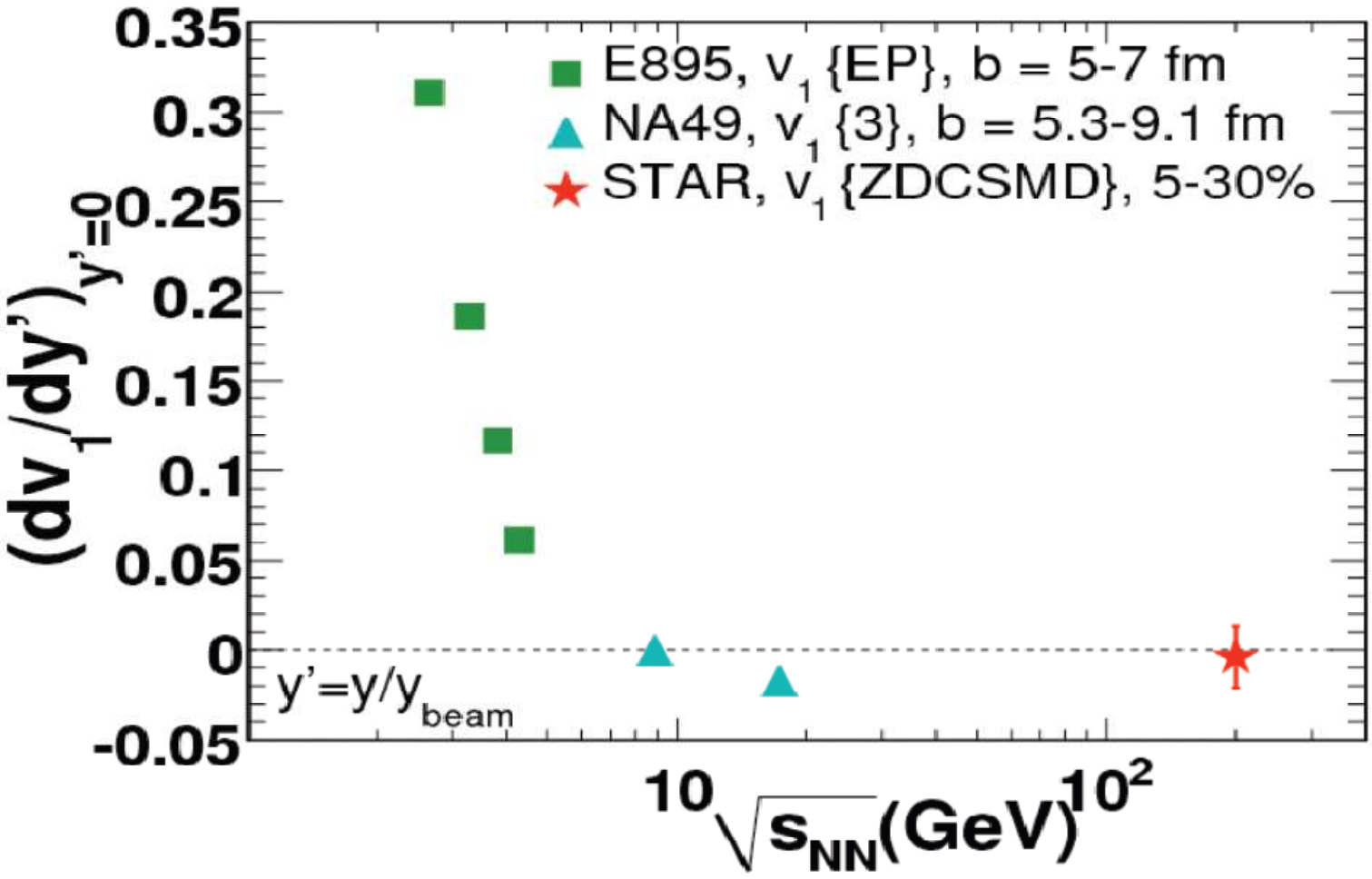
Differences in directed flow (v_1) between AuAu and CuCu are quite small.
Consistent with the 62.4 and 200 GeV result

Directed flow at 19.6 GeV AuAu (0-60%) Collisions



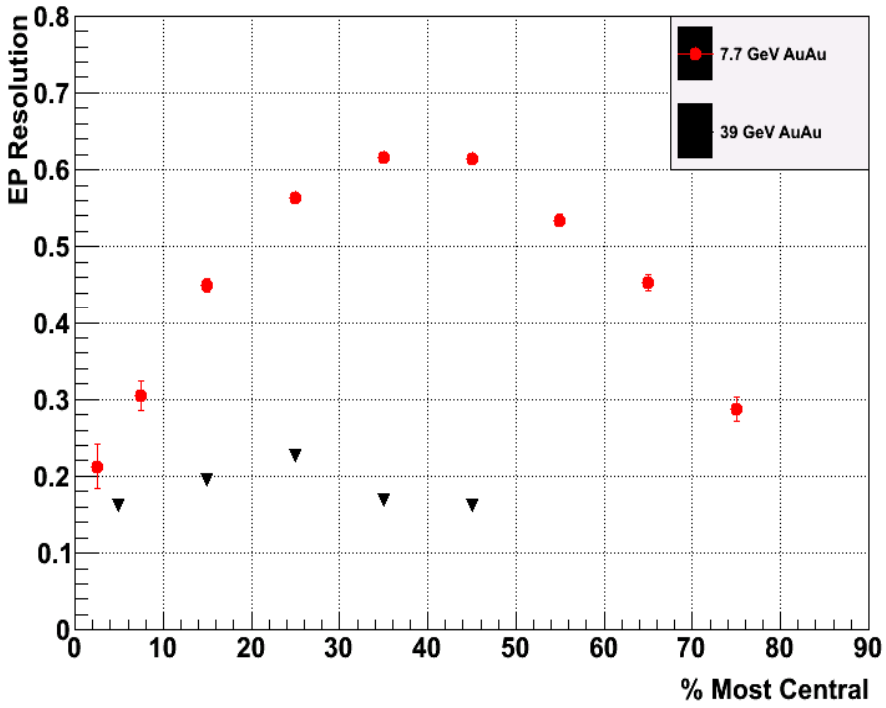
v_1 in 19.6 GeV AuAu collisions from STAR at mid-pseudorapidity

Energy Dependence of proton v_1 slope

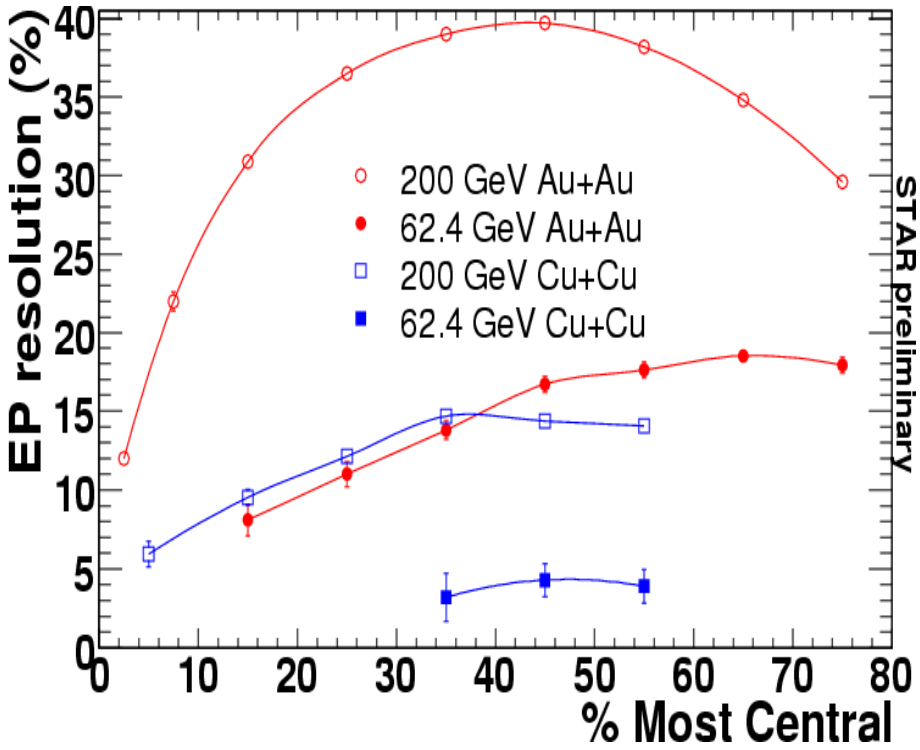


Directed flow from BES

Resolution of 1st-order event plane from STAR BBC



Resolution of 1st-order event plane from STAR ZDCSMD

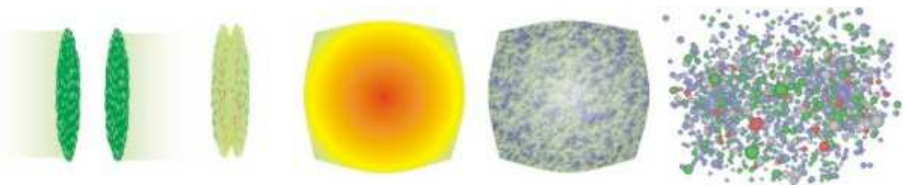


Preliminary analysis for charged hadron directed flow (v_1) at 39,7.7 and 11.5 GeV is ongoing.

Summary/Conclusions

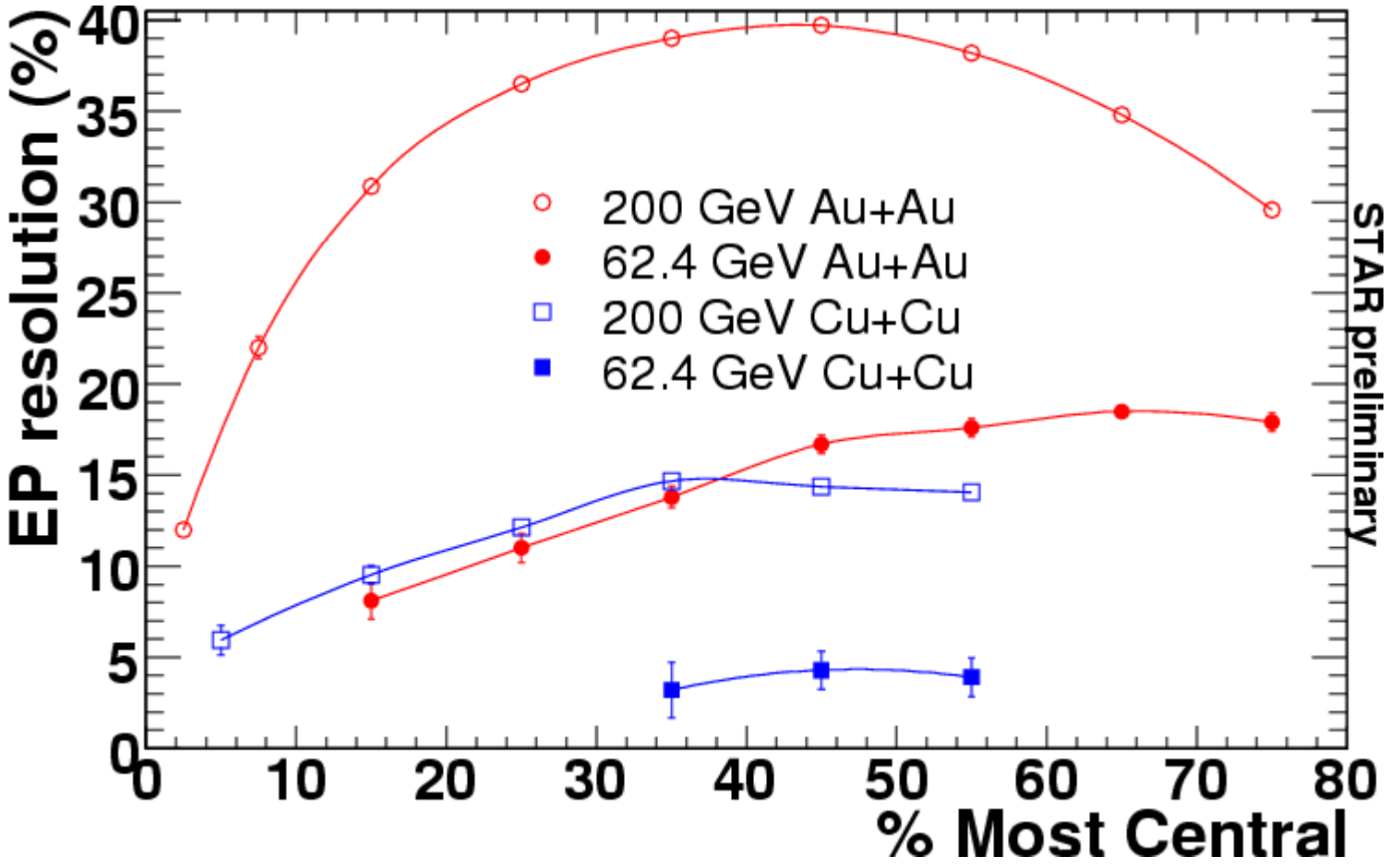
- "Wiggle" / "anti-flow" / "third flow component" gives important hint of phase transition predicted by many models. However, some models without QGP can also predict qualitatively similar effects. Pid v1 can shed light on this.
- Differences in directed flow (v_1) between AuAu and CuCu are within errors. Hydro + tilted source may explain this but other transport models fail to explain it at 62.4 & 200 GeV.
- For 200 GeV AuAu, PID *v1*(y) slopes for produced hadrons are negative at midrapidity which can be explained by anti-flow.
- STAR results at low beam energies follow trend shown by data at 62.4 & 200 GeV (system-size independence + beam energy dependence scales with η/y_{beam}).
- Preliminary analysis for directed flow is ongoing at 39, 7.7 and 11.5 GeV.

Back Up Slides



Resolution of 1st-order event plane from STAR ZDC-SMD

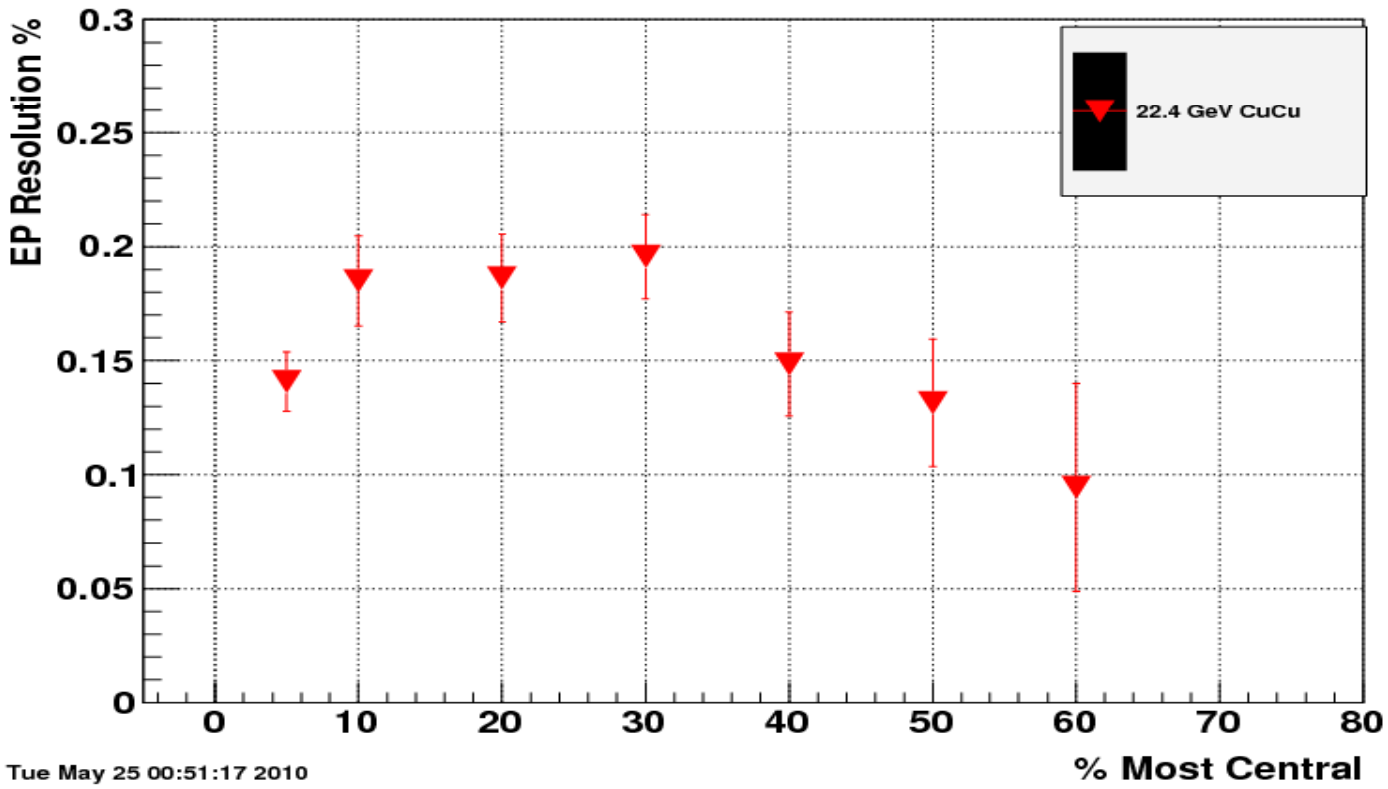
Full EP resolution $\cong \sqrt{2\langle\cos(\psi_a - \psi_b)\rangle}$ **depends on spectator v_1 and the number of hits falling on ZDC-SMDs.**



22

Resolution of 1st-order event plane from STAR BBC

Full EP resolution $\cong \sqrt{2\langle\cos(\psi_a - \psi_b)\rangle}$ **depends on spectator v_1 and the number of hits falling on BBC.**



STAR Detector